U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN No. 257.

SOIL FERTILITY.

AN ADDRESS DELIVERED BEFORE THE RICH NECK FARMERS' CLUB, OF QUEEN ANNE COUNTY, MARYLAND.

BY

MILTON WHITNEY,
Chief of the Bureau of Soils.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1906.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., April 20, 1906.

Sir: I have the honor to transmit herewith a paper entitled "Soil fertility." This is an address given before the Rich Neck Farmers' Club, of Queen Anne County, Md., in which an endeavor was made to place in the hands of the practical farmer the results of recent investigations of this important problem couched in simple language and without a discussion of the technical scientific details upon which the conclusions rest.

In view of the many inquiries received by the Department of Agriculture from farmers in all parts of the country seeking information as to the best methods of maintaining the fertility of soils and of determining the manurial requirements of soils, it would seem that the present paper might prove of value in meeting this demand if afforded a wider audience than that originally addressed. With this in mind I recommend its publication as a Farmers' Bulletin, preserving the style of address and discussion as more effective than a formal presentation of the facts.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

SOIL FERTILITY.

The maintenance of soil fertility, upon which you have asked me to address you, is a very difficult subject to discuss fully in a meeting of this kind. It is a subject so intricate in details and so dependent upon local and variable conditions that it does not lend itself to the didactic treatment of a popular address. Agriculture is an art and not a science, but it is an art that can be and should be largely influenced and directed by scientific investigations and thought. I see no reasonable prospect of agriculture itself ever being more than an art; that is, it will never be founded upon the exact lines which we recognize in an exact science. I shall be glad, however, to speak of certain general features of the essential and broadly applicable laws of soil fertility that the Bureau of Soils, with its large force of field men and its large force of chemists and soil physicists, has investigated in the last twelve years. We think that as a result of this work we understand far more about the principles of soil fertility now than we ever have before, and I wish to give the results in words as simple as possible. You need not necessarily believe everything I say (because I can not say truly that I *believe* everything myself, but only that our opinions seem reasonable deductions), but I wish you to think about what I say and see if it appears reasonable to you, and if it harmonizes with your own experience on your farms. I have to offer you in the latter part of my address, after discussing the principles of soil fertility, a method we have devised for determining the manurial requirements of soils. I think you farmers can use this method, and if it proves to be of use on the farms, if you can handle your fertilizer problems as you are handling your corn-selection problem, I think it will be a great benefit to the art of agriculture.

In speaking of the fertility of soils I shall have to ask you to permit me to review some of the important questions of crop production.

DEFINITION OF FERTILITY.

Fertility and crop production are different terms. Fertility is a property inherent in the soil; it is what the soil is capable of doing if it is under the best possible conditions. The yield of crops, on the

other hand, is not dependent upon the fertility alone. Several of you can take the same soil and get different yields, although you are working with a soil having the same fertility. If your seed is not properly selected, if your planting season is too early or too late, if the soil is not properly cultivated, if the climatic conditions are not favorable, your crop yield may be affected, but the fertility of the soil—that inherent power of the soil under the best conditions to produce a crop—will not necessarily be impaired. So I am going to speak to you now, not of crop yields, but of the fertility of the soil, the power that resides in the soil under proper conditions to produce a satisfactory crop. I am not going to discuss to any great extent the texture of the soil, which determines so largely the kind of crop you should grow, or even the important methods of cultivation, which control the yield and even affect fertility, as it would be impossible for me, in such an address as this, to cover all of the factors that make for a good crop. The fertility of the soil is dependent upon four principal facts, viz: Plants must breathe; plants must drink; plants must feed; plants must have a proper sanitary environment.

PLANTS MUST BREATHE.

Of course we all understand that the breathing of the plant is mainly through its leaves; but the soil also may be a very important factor in the breathing of plants, as it is necessary to have a supply of oxygen around the roots. Physiologists differ as to the office the roots have in regard to the absorption of oxygen. Whether it is a true breathing, the taking of oxygen for the plant economy through the roots as through the leaves, has never been decided; but it is unquestionably a fact that roots of cultivated plants require oxygen around them for their healthy growth. We know perfectly well that cultivation of the soil is important or necessary for the best development of many crops, and we say that it is in order to introduce oxygen and make possible the introduction of more water into the soil.

The investigations of the Bureau of Soils seem to indicate that the actual supply of oxygen to the roots may not be the only or even the most important function of cultivation. It seems necessary not only to introduce air into the soil, but by stirring the soil to permit the escape of noxious gases that are perhaps given off by the plants themselves or produced by bacterial action on the remains or excreta of plants. In a crowded room a person begins to feel drowsy, languid, and his head begins to ache. We speak of these sensations, usually, as due to deficient ventilation, too little oxygen, the oxygen having been partly used up, and to an accumulation of carbonic-acid gas; but physiologists now believe that this is not the true explanation,

but that the person suffers because there are gaseous emanations from the lungs that are deleterious to human beings. The plant is exceedingly sensitive to gases. On the streets of Washington one of the principal causes of the death of trees is leaks in gas pipes; every year hundreds and perhaps thousands of trees have to be removed, and the usual cause is a leaking gas pipe. The amount of gas is so small that it can not be detected by the odor, but the influence of the gas on the roots is so pronounced that the tree suffers and is likely to die. It seems probable that the ventilation of the soil is not only to allow air to enter but to allow gases formed in the soil to escape.

Furthermore, air must enter not only for the use of the root itself, but also to oxidize the organic matters given off by the plants—to preserve the proper sanitary conditions in the soil—as I shall explain later. Ventilation to remove noxious gases might increase the yield without affecting the fertility. Ventilation for the purpose of oxidizing organic matter might affect fertility itself.

PLANTS MUST DRINK.

One of the important features of the Bureau's work in the past few years is its investigation of the movement of water in the soil. We have heretofore supposed that the root is fixed in the soil and that the water, with the food material which it contains, moves up to the root in a constant supply through capillary action. We find, however, in measuring the rate of movement of water in a soil moderately dry or in fair moisture condition as regards the needs of plants that the movement is so slow as to be negligible. You would be surprised at the result of a little experiment, which you can easily perform yourself. If you take some soil from the field with what we call an optimum amount of moisture, or the best amount for plant growth, put it in a tumbler, filling the tumbler about half full, and put some dry soil on the surface, you can see the difference in moisture content by the difference in color, the moist soil being darker than the dry. Then, if you cover the tumbler to prevent evaporation you can leave the dry soil in contact with the moist soil and there will be no appreciable interchange of moisture between the moist and the dry layers.

Mr. Walker. That is, if you put the moist soil in the glass first and then put the dry earth on top, packing it down and bringing the two soils in contact?

Professor Whitney. Exactly; the moist earth will hold on to the water so tenaciously that the dry earth will not pull it away. I am not considering here the rapid movement by capillary action and by gravitation of water through a saturated or very moist soil, for you farmers are not particularly interested in the movement of water

in saturated soils, except in your poorly drained bottom lands; but I am speaking of the soil on your uplands and in the fields in which the drainage is at its best for growing crops. A saturated condition of the soil is rarely found, and should never be permitted during the growing season, except during actual rain. I am speaking to you now of the movement of water in soils short of saturation, soils with even less than the optimum water content. That is, I am speaking of soils in which the best conditions have been passed, but which, though they are becoming rather dry, are far from a condition of drought. Such a soil is still so moist as to be coherent or plastic in the hand, and its ability to supply water by capillary movement has been supposed to depend upon the peculiarities of soil texture. That this movement of water should practically cease is probably a wise provision of nature, as the concentration of the solution may become stronger or the dilution less. As I shall tell you later, it appears that plants often throw off poisonous substances, and the soil itself, with its wonderful absorptive powers, actually prevents the circulation of these substances in the solution in which the plant is feeding. To make this statement clear and to show why I lay such emphasis on an apparently obscure point, which, however, I believe to be the key to the fertility problem, let me recall the facts presented to us by the physiologists concerning the development of a root and we will find the wonderful provision that the plant seeks the water rather than the water being moved by the soil to the plant.

The root of a plant is absorbent for water and for mineral matter only at the tip and for a very short distance back from the tip—only a small fraction of an inch. It is something like one-tenth of an inch of the root that actually absorbs water and mineral food. This portion of the root is only absorbent for a few days, probably for not more than three or four days. As the tip is extended into new fields of moisture and plant food, the part that was absorbent yesterday ceases to be absorbent to-day. There is therefore no reason why water should move up to the plant from any considerable distance, for the plant itself constantly moves its feeding roots out into new fields.

Mr. Walker. That applies to all plant growth?

Professor Whitney. Yes; it applies to all cultivated crops.

These are interesting points which I tell you, not simply because they are of scientific interest, but because I think if I can get you to see the soil as I do, to look into the soil and the economy of the plant and its habits of growth, you can grasp some of the problems in soil fertility that we have heretofore found most difficult. There is another interesting provision in the drinking of plants, which is that after this root tip has progressed, after it ceases to become absorbed,

ceases to be of use in taking up food and drink for the plant, it immediately corks over; it puts on a hard layer of cork cells, large cells called "balloon cells," full of air, to prohibit the further entrance of water or other material from the outside into the roots. The reason for this (if we can speak of the laws of nature in this way), or the result of this, is to prevent certain substances thrown off by the plant from reentering its tissues; the plant protects itself against its own effluvia. And here we see the importance of the absorptive power of the soil, which permits it to seize and hold with great tenacity organic matters given off by the roots and prevents the active circulation of water containing the excreta of plants except in dilute solutions following rains. This I shall speak of again when I discuss the sanitary environment.

PLANTS MUST FEED.

I am now coming to one of the most interesting parts of my story—the feeding of plants, which I think will interest all of you who deal with the soil and with fertilizers. The chemical analysis of soils and its value in its application to the production of crops has been long a subject of discussion. When the Bureau of Soils began its work on the soil survey we knew that we must study the soil, that we must be able to interpret the soils that we mapped or there would be but little excuse for the soil survey. On the other hand, if we could understand the soil, could understand its relation to the crop, we should then not only have the advantage of the soil survey in classifying the soils, but also be able to tell what the peculiarities of those soils were, how they should be cropped, and how they should be treated. I believe that through the results of our investigations during the last twelve years we are beginning to understand clearly the chemistry of the soil. It is exceedingly interesting, but it is entirely different from our former conceptions of it. We are changing our ideas about the chemistry of the soil as we are changing our ideas about the nature of diseases and about physical forces and physical laws which we thought were perfectly understood.

In the first place, our text-books have taught us, if not in so many words at least in meaning, that the soil was the product of the decomposition of the rock; that the soil was a completely decomposed rock. The soil is nothing of the kind. The soil itself is an unconsolidated rock containing the minerals which were present in the solid rock from which it was derived. I have seen soils in California precisely like your Norfolk sand or your truck soil here on the Eastern Shore, but derived in place, or with a slight amount of washing, from granite rocks; and the particles of sand, no larger than your sand particles here, were perfectly formed minerals as existing in the original rocks.

Mr. Walker. They had disintegrated?

Professor Whitney. They had disintegrated, but only slightly decomposed. There is the point where we were misled—in thinking that the rock had to completely decompose. It first had to disintegrate, but not necessarily decompose to any great extent. We can, with our powerful microscopes and our perfect arrangements for seeing and identifying small particles of matter, identify in our clays the minerals that were originally present in the rock from which the soils are derived. Clays, then, are rock powders containing more or less decomposition products, but, besides these, unaltered particles of all the common rock-forming minerals. These minerals exist as such in the soil. They are soluble, but they are very slightly soluble. They are not more soluble than this glass tumbler on the table, but if I should grind up this glass tumbler into an impalpable powder—Professor Johnson tells about a similar experiment, which was actually performed years ago—about 3 per cent of the substance of that ground glass would go into solution in a volume of water equal to the volume of the tumbler. It is largely a matter of the amount of surface for the water to act on.

Thus minerals are not very soluble, but they are soluble. They are soluble to the extent of about 8 parts of phosphoric acid in a million parts of soil, or 32 pounds of phosphoric acid in an acre-foot of soil. They are soluble to the extent of about 20 or 25 parts of potash per million parts of soil, or that many pounds in an acre of soil 3 inches deep, assuming that an acre of soil 12 inches deep weighs about 4,000,000 pounds.

Mr. Walker. About 20 or 25 pounds of potash per acre? You find that potash and phosphoric acid exist in all rocks that disintegrate?

Professor Whitney. In all soils there are rock particles or minerals containing phosphoric acid and potash, and in all the soil solutions that we have ever examined—and we have examined hundreds of them from all parts of the country—you will be astonished to learn that the composition and concentration of the soil moisture, which is the nutrient solution spread throughout the surface soil of the earth for plants to grow in and to gather their food from—you will be astonished to learn that the concentration of this soil moisture is sensibly the same whether we examine your sandy truck soils on your river necks, your sandy clay wheat soils on the uplands, the Hagerstown clay in the valley of the Shenandoah, or the black prairie soils of the West. These minerals are contributing to the solution in which the plant feeds. As I have said, these minerals are difficultly soluble, but they are appreciably soluble. They are soluble enough to maintain a solution which is amply sufficient for the plants to gather their food from. All soils having, broadly speaking, all of

these minerals in them, have approximately the same composition in their soil moisture.

This is a very astonishing fact, but looked upon in the light of our experiments it is an actual fact, that all soils contain sufficient plant food for the support of plants. Further, when the plant takes into its substance some of the mineral matter from the solution, the solid minerals in contact with the solution immediately dissolve and the solution is restored to its former concentration. The exhaustion of the soil, therefore, is merely a relative phrase and resolves itself into the question of the rate at which the solution can recover itself. I may state to you that the rate is as fast on an acre planted in our ordinary crops as the demand made upon it by the plant.

In order to test this idea and to find out if we were safe in announcing such a fact as this, so revolutionary as regards our former ideas, so inconceivable when we look upon what we have considered exhausted land and the benefit derived from fertilizers, the Bureau of Soils has had parties in all parts of the United States equipped with the most sensitive methods for making these determinations in the field. We have taken out of the soil its own moisture and have actually found similar quantities of phosphates, of potash, of nitrates, and of lime, in the sandy soils of our truck region, in the "worn-out" soils of Virginia, in the fertile limestone soils of Pennsylvania, and in the black prairie soils of the West. We then went into the question of how much plant food is actually necessary, how strong a concentration the solution must have to support a growth of plants, and I may tell you that investigators are not able to say how small the amount of phosphoric acid or of potash in the solution must become, if other conditions be maintained perfectly, before the plant will suffer. Plants have an extraordinary power of absorbing material from solutions. Take the case of the seaweed from which iodine is extracted. Sea water has so little iodine that although we have an exceedingly delicate method for the detection of iodine we can not discover it, even if we concentrate the water to a very small part of its original bulk; but the seaweed can get it and store it up in its tissues from that very dilute solution.

But to return to the soil, if the concentration of the soil solution is constantly maintained by the dissolving of these minerals, a plant can get along with much less than the concentration of our soil moistures. Here is a question upon which I do not want you to be misled. It is not to be denied that plants will not infrequently do better when they are growing in a soil, a nutrient solution, or a soil solution many times stronger than they actually need. Why that is we do not know, but I will give you an illustration: If you send to the Department of Agriculture for some of the nitrogen-fixing bacteria

which it sends out, through the Bureau of Plant Industry, to put on the land to produce the nodules on your clover and pea crops, you will receive a small package of bacteria in a little sealed tube in liquid culture, and two little packages of salts; you are directed to put one of these salts into a certain volume of water and introduce the bacteria, and at the end of twenty-four hours to put in the contents of the other package, which is ammonium phosphate; your bacteria will grow in the most luxuriant way, if the proper temperature is maintained. You put in about a tablespoonful of ammonium phosphate and the bacteria do better. The bacteria do not eat all that phosphate. After they have developed a slight cloudiness in the solution, which is all you can safely wait for, you soak your seed, or you spread the solution on your land. If you wish, you can filter out your bacteria and recover the phosphate, and you can use this phosphate over and over again, and it would be possible, although not practicable, for you to do it for an indefinite period—for a great many cultures of bacteria. Your phosphate would not be sensibly reduced by the bacteria, but the bacteria do better in phosphate of that concentration. You might ask why you should use such an excess of phosphoric acid, and they would probably tell you that in a solution of this kind other forms of yeasts and molds will not develop. In other words, it is antagonistic to other forms which would themselves grow on the sugar and culture salts, if it were not for the presence of this ammonium phosphate. The bacteria do better because the other things do not do so well, and the salt is used as a precaution against the molds that would soon sour and spoil the cultures.

It is an undeniable fact that in growing plants in water culture an excess of nutrient salts always has to be used for the best results. You could take up one of these wheat plants from the field, put it in this pitcher of water, add a little phosphate, potash, and nitrate, and grow it to maturity. Very likely it would produce as much grain as if it were left in the field. The soil is but a medium for the plant to stand in and for it to get a constant supply of nutrient material from, but the plant will grow, under proper precautions, in water, and it is through the study of these water cultures that we have learned a great deal about the supply of food to plants. If we take a plant and grow it in a water culture, the plant does better if we have a solution containing several times more phosphorus and potash than it actually needs to feed on. Why it is we do not know, but granting that the plant does better in a solution stronger than it actually needs as a food, we still have a solution in the soil apparently strong enough for any need the plant may have.

Now we come to a very interesting thing to the farmer. If soils have sufficient food for the needs of plants and if this supply is constantly maintained, as I say, by the solution of these minerals in the soil, then what is the function of fertilizers and what do we mean by worn-out lands or exhausted soils? It is just along this line that the Bureau is working and it is just along this line that we are getting most interesting results, results even now apparently of practical application; and this brings me to my fourth heading:

PLANTS MUST HAVE A PROPER SANITARY ENVIRONMENT.

Plants must have a healthful home to live in. Plants, like animals, throw off excreta, which must be disposed of. We see this constantly in making cultures of bacteria. If we let the bacteria grow long enough they kill themselves by their own products—that you know. We know that when nitrifying fields we need lime to take care of the nitric acid that is formed by the nitrifying bacteria, because if the nitric acid which is the product of the bacteria accumulates they will surely themselves be destroyed. We must put something on the soil to destroy or change their effluvia so that the bacteria can themselves go on working. We must clean out the soils as we do the stalls in our stables. If we do not, the substances given off by the plants, or the substances that are formed from those substances by the action of bacteria, will produce acid substances, will produce what we call toxic or poisonous matters, that will themselves seriously affect if not kill the crop.

That there is toxic material—a poisonous material—in the soil, I think I can prove to you in a very few words. At least, I can make it appear so plausible that you will accept these ideas and will direct your attention in the cultivation of your fields to some of the practical applications that I shall point out. The chemical idea of the exhaustion of a soil is not logical in the light of the experience which all of us have seen, that where fertilizers are applied the soils are not always made immediately productive. You can go into many of the regions of the worn-out soils of our Eastern States and reclaim these soils or make them productive, but not with any amount of fertilizers you can apply. You can give them all the phosphate, all the potash, all the nitrate you desire, but it requires more than that to revive the agriculture on some of these soils. That there are toxic substances in the soil, I think you will grant me from your experience in turning up subsoils. There is no doubt at all that in certain sections of the country certain subsoils are poisonous when incorporated in a soil, and that while deep plowing is very desirable, it is unsafe, after shallow plowing has been carried on for years, to run your plow down and turn up a great mass of subsoil and incor-

porate it in the soil. In a great many cases it will take several years to get the fertility of the soil back to where it was before this procedure. I know of a case in one of the Western States where a railroad embankment was thrown up over a gentleman's lawn. The lawn had flourished for many years, located as it is in one of our fine grass States. This embankment was built across one end of the lawn and remained there for a number of years. Then the railroad was abandoned or the gentleman secured permission to remove that portion of the embankment which covered his lawn. He exposed the surface of his old lawn to the action of the air and sunlight, and it was impossible for him to get grass to grow on it again. He has been trying for years to get grass to grow again on that soil, which was in all effect a subsoil for a number of years by being covered over.

Not only is the subsoil known to be poisonous in many cases, unless it is allowed to lie in small quantities exposed to the air, but muck is often poisonous to the soil unless it is permitted to weather before it is applied. One of the most interesting instances going to show that toxic substances are formed and that what is poisonous to one crop is not necessarily poisonous or injurious to another is a series of experiments of Lawes and Gilbert—which probably some of you have seen or heard of—the growing of potatoes for about fifteen years on the same field. At the end of this period they got the soil into a condition in which it would not grow potatoes at all. The soil was exhausted and under the older ideas it was necessarily deficient in some plant food. It seems strange that, under our old ideas of soil fertility, if the soil became exhausted for potatoes it should grow any other crop, because the usual analysis shows the same constituents present in all of our plants, not in the same proportion, but all are present and all necessary so far as we know. This field was planted in barley and on this experimental plot that had ceased to grow potatoes they got 75 bushels of barley.

In Mr. Walker's front lawn there is a fair-sized maple tree, the lower limbs not coming within 8 feet of the ground, under which the growth of grass is sparse and unsatisfactory. Immediately around the trunk of the tree and following out some of the larger roots, which come close to the surface, the sod is completely gone, and around the tree out to the extremity of the limbs the grass shows a uniformly poor appearance. The lawn in front of a man's residence is always a matter of careful consideration and special care. I am sure Mr. Walker would not grudge the fertilizers if they could restore this part of the lawn to the beautiful appearance of the rest. As a matter of fact, he has applied fertilizers apparently without beneficial effects. The usual explanation of such an occurrence is that the grass will not grow in the shade of the tree

and that the tree extracts so much water and plant food that the grass is starved. This explanation is not logical, for the most marked effect is around the trunk of the tree where the tree takes no moisture or plant food. Other trees on the lawn which are even larger and cast presumably a more dense shade have not affected the grass in the same way. On the grounds of the Smithsonian Institution, of Washington, D. C., I have for years observed this same phenomenon of the grass dying under the trees and find that it is particularly marked under certain individual trees and that on a sloping surface it extends most markedly in the direction of the surface drainage. Furthermore, in observing the actual death of the grass after a rainfall it can be seen that the plant dies from the top downward—that is, the leaves themselves are killed, while the roots may still apparently be alive. Our explanation of this is that the plants are poisoned or killed by the leachings from the tree, which in effect contain the excreta or waste material from the bark and limbs. This, together with substances evidently thrown off by the tree roots, appears to account for and to be the only reasonable explanation of the injurious effects of the tree upon these lawn grasses. The amount of shade cast by the tree does not account for this, for it is as marked on the sunny side as on any other. The amount of water and of mineral matter taken up by the tree does not account for it, for it would be an easy matter to supply both artificially to the soil.

It will be quite impossible and rather undesirable for me to attempt to give you the scientific basis or proof of this idea that there are toxic substances given off by the plants, but perhaps if I can give you a few more illustrations of this kind you can see the point that I am trying to make—that the plant does throw off substances which, unless changed and rendered innocuous or unless actually removed from the soil, endanger the life of the plant.

We come now to an explanation of that peculiar provision in the corking over of the root, which I told you of a while ago and which I said I would speak of again—that is, we know that plants do emit organic substances which are deleterious to themselves, and we know this, that as soon as the absorbing portion of the root ceases to be absorbent the plant covers itself with that impenetrable cork, apparently so as to prevent the absorption of its own effluvia.

I should say that the soil ought to take care of the excrement of plants. It is its business to do so. It is its proper function. Whether it does this through the agencies of bacteria, whether it is due to the abnormal absorptive power of the soil or to direct oxidation, we do not know. It is probably due in part to each. Take a natural soil, a prairie sod; the sanitary conditions in that soil are

almost perfect. In our ordinary soils if we grow the same crop in succession we know that we do accumulate in the soil organic matters that are not humus. It is our experience that black soils are generally more productive than the light-colored soils, as you see in your well-drained black bottoms. Black prairie soils are generally very productive. We say this is because they have more organic matter. Now, the Bureau has found, through its extensive investigations, that there is not so much difference between the organic content of the soil and of the subsoil as we have heretofore supposed. There is no doubt that there is a large amount of organic matter in the subsoil, but it is not in the form of humus. It is in other forms, and in order to improve the subsoil and convert it into a fertile soil one of the first things that we really accomplish through aeration and cultivation is to convert that colorless organic matter, if I may so speak of it, into darker compounds like humus.

We have studied the office of humus in the growth of plants. We have found that humus extracted from our cultivated soils is innocuous to the plant. It is apparently neither beneficial nor deleterious. Humus is a very stable form of organic matter. It remains in the soil for years. It may be exposed to extremes of heat and cold, but still the black color of a black soil will persist. It is much more stable than wood. It is into humus that wood or wood fiber is converted if it is incorporated in a finely divided condition in the soil and goes to an end product—that is, if it goes into its most stable form. I really believe that humus, next to coal, is the most stable form of organic matter that we know of, and if you think this over you will agree with me that when organic matter is converted into humus it is as thoroughly preserved as any organic matter that we have in nature. Ordinarily a soil to which organic matter has been added should, if its condition is favorable to plant growth, convert the most of that organic matter into humus. It is preserved. The humus formation is the natural method of the proper sanitation of the soil. As soon as the organic matter is converted into humus it is harmless to the plant; it is in effect, although not in fact, removed from the soil. While it is in the form of humus it is not harmful, it is not poisonous, but while the organic matter is in any other form it may be or may become harmful to the plant. The humus, apart from the physical effect it has in loosening up the soil and the absorbing effect it has in holding water, which may greatly increase the yield of crops, appears to be the form of sewage disposal for the crops. Through the aid of bacteria or by direct oxidation the excreta thrown off by the plant are just as effectually disposed of, so far as any toxic effect they may have on the plant is concerned, as if they had been thrown into the bay, and a soil that will produce

humus is a fertile soil, because it is a well-drained soil so far as sanitation is concerned. Is that point clear?

Mr. Harris. I would say you might make it clearer if you would state the possible length of time required for vegetable matter to become humus.

Professor Whitney. We have a marked difference usually between the soil and the subsoil in the matter of color. The soil spreads out over the surface of the earth as a superficial covering that is somewhat darker, by reason of the humus it contains, than the subsoil. We are not cultivating the soil that our forefathers cultivated; but the soil can be maintained in spite of erosion. If the soil were all removed, we could make artificially a new soil. You know perfectly well that if your soil were removed over night and you had a subsoil to convert into a fertile soil you would begin, if it were a garden patch, by spading up the ground. Spading is better than plowing, because it is more thorough and more efficient; so, I say, if it were a garden patch you would begin by spading, and you would throw your soil up to the air, and you would find by watching it that it would soon begin to darken—the raw, red clay would begin to darken. The lumps would first become partly dark red and partly light red, as it was originally. You could doubtless pick up some subsoil here that is on the verge of being changed to soil through the change of its organic matter into humus. Through aeration this organic matter is changed to humus and the subsoil becomes a true soil. On the piece of subsoil we are speaking of it would require about three years—unaided by manure or fertilizers; through natural means of oxidation—to convert into humus the organic matter that was there and leave the soil in good condition for crops. Does that answer the question?

Mr. Harris. Yes, sir; but we do not want to wait three years. We want a quicker method.

Mr. Walker. Some of us have been waiting longer than that. Do you mean that with the action of the atmosphere and rain and with fertilizers it would take three years to change the nature of a subsoil to soil? By use of the spade, sunshine, air, and water, do I understand you can make it productive in three years?

Professor Whitney. Not in all cases. In many cases you can take a raw subsoil and by spading it up—preferably, of course, with a little manure—make it productive.

Mr. Walker. There is the point.

Professor Whitney. You can in about three years produce a soil again where there was a subsoil before.

Mr. Walker. You would select a good piece—you would not take a barren soil?

Professor Whitney. Well, of course, I would not recommend this as a practical method. I should use manure or green manure to hasten the change.

In the disposal of the substances thrown off by plants the absorptive power of the soil plays a very great part. The soil itself is capable of holding on with great tenacity to organic substances, so that it is impossible to leach them out with water. For example, if you take a soluble dyestuff and shake up in the solution some soil the soil will take out the dye and allow the water to filter clear, although the dye is exceedingly soluble in water when the soil is not present. The soil holds on to these organic compounds given off by the plant in the same way that it retains the dye, and, as the root corks over immediately after throwing them out and the movement of water in moderately moist soil is exceedingly slow and almost negligible, the root passes safely its own excreta.

We have here a small pot holding a pound of soil, of which I shall explain the use later, in which we grow plants for a short time, and if we grow six wheat plants in the soil for three weeks and cut them off when they get about as large as this [exhibiting pot with growing plants] and immediately grow six other wheat plants in the same soil we get about half the yield or half the size of the first plants. In other words, that amount of soil is exhausted in three weeks by the growth of six seedling wheat plants, if we measure its fertility with a crop that immediately follows it.

Mr. Walker. It goes to show that your plant absorbs the fertilizer in that receptacle?

Professor Whitney. That is the old idea. Now let me tell you the new idea. After I have grown six plants, suppose we take them out and put in six more seedlings and grow beside them another set with fresh soil. I will get twice as much in the fresh as in the other soil. We have exhausted the plant food, according to the old idea. It ought to be possible to supply sufficient food for the next crop, for our laboratories have sufficient phosphoric acid, nitrates, etc., so that we can furnish fertilizers for the pound of soil. It is possible to put in all the food the plant needs; but when we have introduced all the plant food that may be required by the second crop, and a great deal more, we do not increase in that soil, which I have in this pot, the growth of the second crop after another crop of the same kind has just been removed. Now, what can we do? We will take that same soil and mix it with cowpeas. If we have grown one crop of wheat, mix the soil with cowpeas finely chopped up and thoroughly incorporated, at about the rate at which you make your applications in the field, and you will get double the crop in the "exhausted" soil so treated that you will from the fresh soil as it came from the field;

and then after your application of cowpeas you can grow three crops of wheat on the same soil before the yield will go down to what it was in its original state. This instance in which fertilizers do not improve the soil after wheat has been grown is not a general case, but is used as an illustration only for this particular sample that I have in the pot. In other soils fertilizers may act as beneficially as the cowpeas. In other soils still cowpeas may not act beneficially.

Mr. Walker. That is a remarkable claim for cowpeas.

Professor Whitney. We have gone further and have tried to see whether it was the salts that the cowpeas had taken from another soil and put into this soil or whether it was the effect of the decomposing organic matter.

Mr. Walker. Were the cowpeas ground and mixed green or cured?

Professor Whitney. They were applied green, as we have found them to be generally much more effective green than when dried. To see whether cowpeas were beneficial from the amount of salt they had taken from the soil in which they had been grown or whether it was due to the organic matter itself, we burned the cowpeas, leaving the potash and phosphoric acid, and added the same amount of nitrates that would have gone in with the cowpeas, and we failed to improve our soil. We have not only done that, but we have been able by other means to separate the salts from manure and from cowpeas and apply the salts separately from the organic matter, and it is not the salts that do the greatest good in cases of this kind. It is the organic matter itself that improves our soil. It is not the salts that you add in your manure, but the organic matter. I am making a very broad statement, that is not applicable to all conditions. There is no doubt that fertilizers do act as plant food in many cases, that stable manure and green crops, through the salts they contain, may act as plant food, but we have proof that a large part of the favorable action of cowpeas and of manure is due to the organic matter itself and the changes it causes in the soil.

The organic matter of manure and of green manure, being easily convertible into humus, seems to purify the soil, scour it out, clean it—seems to remove or change the toxic organic substances left by the preceding crop. The fact that the soil is not exhausted of plant food is shown by the fact that if you replace all the plant food of this particular soil I am speaking of, you can not get a second crop equal to the first crop; but if you put in organic matter, such as you have in cowpeas and such as we have in a chemical, pyrogallol—which possibly you all know, a substance used in developing photographic plates, which contains no plant food, but which will apparently act precisely as the cowpeas—you can grow three successful crops of wheat on the soil before it will again return to its former state. Do

not understand me as recommending pyrogallol as a substitute for cowpeas. It is an expensive chemical used merely in our scientific experiments.

Mr. Walker. Let me ask whether, in applying cowpeas or clover, you would flush under or plow under?

Professor Whitney. The best possible thing would be to grind it, cutting it very fine while it is green, and mix it thoroughly with your soil.

Mr. Walker. Through a manure spreader, perhaps?

Professor Whitney. Precisely. Of course I realize the expense of handling the crop. It is not that I am advocating this; I am merely using it as an illustration of my story of the fertility of the soil. I do not want you to understand that I am advocating the use of pyrogallic acid, which costs $2 a pound, or the grinding up of your cowpeas as we do for our pots.

Mr. Walker. What the soil needs is something to cleanse or purify it?

Professor Whitney. Something to remove or change these toxic substances. I hope before long we shall have very strong proof of what I am about to say. I hope we shall be able to identify some of these toxic substances. We see them through their results, we handle them, but we have not yet been able actually to extract them and lay them in a receptacle and say, "This is a toxine." The amount is probably so small that it will be difficult to separate enough to enable us to study it as we should some salt or mineral substance. These toxic substances, like the ptomaines or the tox-albumens in decaying meat, that are so poisonous to the human system, are difficult to separate and study. These substances are all more or less easily changed, easily broken down, easily destroyed, and it is our belief that fertilizer applications in many cases act in much the same way that manure and cowpeas do in changing these toxic substances, namely, in affecting them in some way so as to purify the soil. Many of these substances we use as fertilizers have the peculiar power that nitrates have of readily acting on organic substances. You know how soon a jute bag rots in which you have acid phosphate or kainit or nitrate of soda if it is stored where there is the least amount of moisture; just so, apparently, these small amounts of fertilizers we add to the soil have their effect upon these toxic substances and render the soil sweet and more healthful for growing plants. We believe it is through this means that our fertilizers act rather than through the supplying of food to the plant.

Mr. Harris. Chemically, do they act in that way?

Professor Whitney. I am speaking of their chemical action.

Mr. Harris. A direct supply?

Professor Whitney. It is an indirect action rather than a direct action.

Mr. Anthony. Could you enlighten us as to what form of fertilizers we had best apply to correct this poisonous condition you have referred to?

Professor Whitney. I am going to give you that in the last part of my address.

In seeking an explanation of some of the principles of soil fertility, we found that the soil moisture of our different soils, whether they were fertile or whether they were poor, had essentially the same amount of phosphoric acid, potash, and nitrates. It was an anxious time when we reached these conclusions, because we ourselves did not see how it was possible. We found that we were right up against the problem of commercial fertilizers. I have attempted to show you the way I believe fertilizers act and the reason we use them. They are in a great many cases a ready means of purifying the soil. I think that is the way stable manure and green manures act. I think that is the principal office of nitrate of soda, potash, and phosphoric acid; but they do not all act alike on the same soils. We are working now on a soil in Iowa which with stable manure every time produces a smaller crop than without. That seems strange to you. It is a very unusual thing and I do not wonder you smile, but it seems to be a fact and is borne out by field experiences. Their stable manure plots produce a smaller yield than the check or untreated plot.

Mr. Walker. Is that on rotation of crops, or is it confined to a succession of the same crop?

Professor Whitney. That is a general statement. As a rule they get no benefit or even a slight deleterious effect from manure.

These principles I have laid down give a plausible reason for the rotation of crops. If there are toxic substances thrown off by plants which the soil is not in a condition to remove or change at once, we try to hasten it by cultivation, by aeration, by oxidization. In many of our systems of rotation, especially in Europe, the need of fallowing or resting the soil is recognized. When the soil is allowed to lie fallow almost invariably beneficial results are seen. The benefits may not be sufficiently great, as we believe in this country, to justify loss of the crop, but fallowing is generally beneficial to the soil. There is another way in which the fertility of the soil can be maintained, viz, by arranging a system of rotation and growing each year a crop that is not injured by the excreta of the preceding crop; then when the time comes around for the first crop to be planted again the soil has had ample time to dispose of the sewage resulting from the growth of the plant two or three years before. This, I think, is the basis or reason in many cases for our crop rotation, viz, that these

excreted substances are not toxic alike for all plants, and the soil has time to recover its tone and cleanse itself. I have told you that barley will follow potatoes in the Rothamsted experiments after the potatoes have grown so long that the soil will not produce potatoes. The barley grows unaffected by the excreta of the potatoes, another crop follows the barley, and the soil is then in condition to grow potatoes again.

In other experiments of Lawes and Gilbert they have maintained for fifty years a yield of about 30 bushels of wheat continuously on the same soil where a complete fertilizer has been used. They have seen their yield go down where wheat followed wheat without fertilizers for fifty years in succession from 30 bushels to 12 bushels, which is what they are now getting annually from their unfertilized wheat plot. With a rotation of crops without fertilizers they have also maintained their yield for fifty years at 30 bushels, so that the effect of rotation has in such case been identical with that of fertilization.

Mr. Walker. What is the character of their fertilization?

Professor Whitney. They have an elaborate mixture containing phosphates, potash, and nitrates.

Mr. Walker. About everything, in hopes of striking it right with one or the other?

Professor Whitney. I can hardly say that.

Mr. Dewberry. What was the rotation?

Professor Whitney. It was a four-year rotation of wheat, roots, barley, clover or beans or fallow, with wheat every four years.

Mr. Dewberry. A different crop every year?

Professor Whitney. Yes.

PARAFFIN-POT METHOD OF TESTING THE FERTILIZER REQUIREMENTS OF SOILS.

Now, the question is, What fertilizers shall we apply to our field? That is the great thing to get at; that is the ultimate use of the soil survey and of soil anaylsis. If our explanation of the way in which these fertilizers act is correct, then we must realize (and I think it is not a difficult thing for us to do) that nitrates will attack one kind of organic matter, phosphates will attack another, and potash will attack still another, and that sometimes a combination of two or of the three is more effective than when one is used. Sometimes when none of these fertilizers will restore the fertility we may have to resort to green manure, or to stable manure, or to deeper cultivation for the furthering of aeration, or to some more drastic means than this. It is evident that toxic substances are thrown off by plants or formed in the soil from plant excreta. These are probably not simple substances, but a mixture of substances. Different plants

throw off different things, or different products are formed in different soils. Not only do these substances vary with the nature of the plant and the nature of the soil, but also with every season, for we know perfectly, those of us who have used fertilizers, that fertilizers are more effective one year than they are another; that one time one thing will do but will not another, and we can only decide after a period, say, of ten years, what fertilizers it is safest to apply. If we could get that information for any particular year and it was a safe guide for the next ten or twenty years, how many of us would wait? We would try a plot and see whether these fertilizers are efficient and settle our fertilizer problem at once and for all time, so that when a man sold his farm he could get a bonus for the formula of the fertilizers needed by the soil. But the season when this fertilizer was efficient has changed, so that we do not get the same results, and the next year the seasonal influences are so great that we are befogged in regard to the fertilizer. So in judging of the kind of fertilizers needed to improve the fertility of the soil—I do not mean to increase the yield—it is necessary to eliminate as far as you can the seasonal variations, so that you can get at the effect of the fertilizers and the soil when they are put together. We have found a very simple method by which the fertilizer requirements of the soil can be tested, and it appears to be very satisfactory. It has been tried at several of the experiment stations against their plot experiments. We now have parties at a number of the stations and are studying the results of what we call the "wire-basket method," or the paraffin-pot method, in comparison with field experiments that have been going on for many years.

Mr. Walker. This is the method that Mr. Bonsteel referred to at Chestertown? Mr. Harris, you remember Professor Bonsteel's address?

Mr. Harris. Yes.

Professor Whitney. I have here a little wire basket made of wire netting with about one-eighth inch mesh. The basket is made by cutting a strip of this wire netting—an old window screen would do equally well, because the wire is not the important part at all, as I shall show you—and riveting the ends. The bottom is just laid in. After this little basket is made the rim is dipped in melted paraffin until a little ring or band of paraffin is formed around the top. It is then filled with the soil that is to be tested, taken from the field and mixed thoroughly, so that several pots can be filled from the same sample. When the soil is put in the baskets it must have about the right amount of moisture—that is, must be in about its best condition.

Mr. Walker. You mean the best plowing condition at which the soil would turn up, the condition in which it works up best?

Professor Whitney. Yes; the condition in which it would form the most perfect seed bed.

The soil is put into the pot and is pressed down so that it nearly fills the pot or comes within about one-half inch of the top and the loose soil is brushed off the sides. The pot is then dipped into melted paraffin quite hot. The paraffin should be quite hot, so as to form a perfect paraffin coating. The wire ceases to play any part except as a means of sustaining the soil. It is really a paraffin pot reenforced by wire—really an earthen pot, because the paraffin forms a hardpan on the surface of the soil so that to all intents and purposes you have an earthen pot the sides of which are the soil itself. It is a simple little invention, but it is very efficient. When we tried to test the fertility of the soil by growing seedlings in soil in an ordinary tumbler, which we used at first, the roots came out and went around the edges of the glass where they could get air. Under those circumstances, if you grow seedlings in a poor soil and in a fertile soil, you will see practically no difference; the poor soil would produce about as well as the good. But if you seal them up so that the roots can not come out and get air, then the true characteristics of the soil are shown in the development of the seedling plants. It is just this little trick of sealing that little air space so that the roots can not grow in it but are confined to the soil that has enabled us to get all the characteristics of the field conditions in these little pots, when we could not get them in the ordinary earthenware or glass pots because of the more perfect aeration. So that we see here again the efficiency of aeration, for between the soil and the sides of the ordinary earthenware pot or tumbler these toxic substances are completely destroyed. I have here two pots of soil in which seedling wheat plants are growing. The plants are of the same age, planted at the same time in the same soil, one pot fertilized and the other not fertilized, and from their appearance it is easy to see that the application of fertilizer in this case has been beneficial. These plants have grown as far as they can in this volume of soil. They will not mature. We do not consider it necessary for the study of the soil that they mature. We use the plants simply as an indicator to show whether the fertilizer has benefited our soil. The plants quickly respond and tell us that it has in this case, or that it has not in another, and from these indications and by adjusting the amount or kind of fertilizer we are able in a short time to determine the fertilizer requirements of a soil. We can tell whether potash is necessary and whether it does better in combination with other substances, and can get our information in from ten to twenty days.

Mr. Klinefelter. How would you gauge the quantity of fertilizer to apply to each basket?

Professor Whitney. We put on about the field applications, possibly a little more if we want to bring out strongly its influence on the plant; but the result is as apparent in these pots as it is in the field, and we get the effect in these pots that we do in an ordinary season in the field. We can get results in three weeks in these pots that it sometimes requires ten years of field experience with changing seasons to arrive at. It eliminates all variations in the season. We want to know the fertilizer requirements of the soil.

Mr. Walker. If we make a test, in ten to twenty days we shall know what the soil needs if the season is favorable. You mean it would take that time to carry on the experiment; that it would be well to take a sample in one of these little receptacles and see the growth under that condition. If the plant makes a weak growth, probably it would take another experiment, with the application of certain mixtures, or, if we contemplated using phosphate, we should see what its effects would be, and then if it grew vigorously we should put phosphate on. Is that the idea?

Professor Whitney. Yes; the amount of lime or acid phosphate that we put in that pot corresponds to the amount we intend to use in the field. I do not recall the proportion of fertilizers we use to each pot, but we have the information in Circular No. 18 at the office, and I will take pleasure in sending it, with explicit directions for testing soils, to Mr. Walker for distribution to the club members or to any others who may write to me for it.[a] The actual weight of the soil is rather immaterial—that is, we can mix up 5 pounds and fill five pots with a pound each; that is sufficiently close. What we actually do is not to rely on one pot, but upon five pots in each treatment.

We wish to test, for example, the fertilizer requirements of the soil of this field. If you have a sample of lime and want an indication as to whether it would be beneficial for your soil, take from two to five pots full of soil without lime and the same number with lime mixed in about the proportion you would use in your field application, or twice that proportion, or three times that proportion; then plant your wheat seedlings and watch them grow. Inside of ten days or two weeks the plants will indicate whether this soil has been benefited by the lime and how much lime it is best to use.

So with other fertilizers. The kind, the amount, or the combination that will increase the fertility of the soil and put it in better condition for plant growth can be determined by these simple tests with this paraffin-pot method and may be used as a safe indication for field tests or actual field work. You must not, however, expect

[a] See the appendix to this bulletin, which gives the essential portions of Circular 18 of the Bureau of Soils.

too much of this method. While the seedlings appear to be good indications of the effect of the fertilizers on the fertility of the soil, they will not tell you the number of bushels you will get from your crop, and you should not expect this from my definition of fertility and crop yield. Sometimes we find that lime, manure, and fertilizers do not respond in the pots as they do in the field, but in such cases we have pretty clear evidence that the trouble in the field is due to the improper physical condition of the soil, and when the soil is put in perfect physical condition, as we have it in the pots, it will produce a satisfactory crop, sometimes even without fertilizers. With less favorable physical conditions in the field the soil responds to manure, lime, or certain fertilizers, so that we are able in a measure to test by this paraffin-pot method whether our soils are in the best physical condition and whether the cultural methods we are using in the field are the best for that soil; but, remember, the indication you get from the pot as to the effect of the fertilizer is primarily the effect of the fertilizer on the fertility of the soil as measured by the growth of seedling plants.

Mr. Walker. If we get the plant, we can safely take a chance with the yield.

Professor Whitney. I think you can.

We have done a great deal of work with this basket method, and we are satisfied that it is reliable and can be used to give just the kind of information that you need. It is not an exact scientific method. You are never going to get your fertilizer problem down to a scientific basis. It is at most an art, and the only thing you can do or reasonably hope to do is to improve your art, so as to be as successful as possible, and there will always be great chances that will have to be taken. You can also test with these pots the effect of letting the lime or fertilizers stand in contact with the soil for some time before planting. You can let your soil stand in covered dishes slightly moist for two or three weeks or longer, keeping it in good, moist condition for planting, but not actually planting until you get ready.

We seal these little pots with paraffin paper disks fitted around the plants, so as to prevent evaporation. We put a little sand over the surface, so that the surface will not bake, and then we weigh them every day and determine the amount of water lost through evaporation. The amount of water lost is proportional to the amount of leaf surface they form, so that if one set of pots loses 1 ounce and another 2 ounces under the same climatic conditions, there is very likely twice as much growth in the second set of pots. This enables us to measure accurately the growth. You need not seal your pots nor weigh them as we do, for you can see the effect in the appearance of the plants.

Mr. Klinefelter. What is the idea about putting the paraffin around the rim first like that?

Professor Whitney. To complete the side of the pot above the soil. You could not dip down so deep in the paraffin after the pot was filled with the soil.

I think that through the use of this method, if you gave the same attention to putting up three, four, or five baskets without fertilizers and the same number of baskets with the fertilizer you proposed to use—if you gave the same attention to details and took up the work in the same spirit in which you are taking up your corn selection, you would be able to select fertilizers for your field with the same benefit that you hope to get from your selection of seed. I would very earnestly commend this simple method of testing the soils as a very efficient means of indicating the fertilizer requirements. It is at least much more efficient and more practicable than a chemical analysis of the soil.

QUESTIONS AND ANSWERS.

Mr. Walker (chairman). Gentlemen, we have all listened to the very interesting and instructive address of Professor Whitney, and we would now like to take up, with his permission, a cross-examination. Any questions that suggest themselves I would like you to ask, and I feel sure that Professor Whitney will give such answers as meet the conditions. I made several notes during his address. He says that the plant seeks the water and not the water the plant. We have been accustomed, as I understand it, to attract moisture to the soil largely through cultivation. Am I right? In attracting the moisture, is it that we are bringing water to the plant, or is it preparing the soil for the plant to go to the water?

Mr. Dewberry. I understand that we cultivate to preserve moisture. I have always understood it to preserve what is there in the soil. Our agricultural editors and teachers advise us to keep moisture in the soil by keeping the soil in good tilth. Suppose Professor Whitney tells us about what is right to do or what we are doing when we cultivate the soil.

REASON FOR CULTIVATING.

Professor Whitney. The Bureau has done a great deal of work in this line of soil physics, especially on the reason for cultivation and the effect of cultivation. Aside from the question of aeration which I touched on a while ago, the effect of cultivation is, in the first place, to improve the condition of the soil; particularly to render it more open and porous, so that it can absorb more of the rainfall and permit the roots to grow with the least possible resistance. When you culti-

vate you increase the apparent volume of the soil; that is to say, if you dig a hole in the soil, as in preparing for a fence post, it is a very difficult matter to put back the soil that you take out. When you loosen the soil by plowing or harrowing you leave it in a much more bulky form and it absorbs much more of the rainfall, not only because it contains more volume of space for the water to occupy, but because the grains of soil being pushed apart there is actually more surface to hold on to the water. The effect of subsequent cultivation is to dry out the surface by exposing it to the air. We used to say that it was to break the capillary connection. You can not thus break the capillary connection in the soil, for when you put the soil back you have reestablished capillary connection; but this is what you do accomplish—you accomplish just the thing I advised you to try in putting some moist soil in the bottom of your tumbler and covering it with dry soil. The moist soil, so long as it is not actually wet, holds on to the moisture so tenaciously that it will not move up to any appreciable extent into the dry soil. You remember what I told you about the exceedingly slow rate of movement of water even in a moderately moist soil. If we have the surface soil dry, so that water will not come to the surface of the land, then the evaporation of water will be confined within the soil, and the vapor so formed will have to diffuse out through the dry layer, which is a slow process. The water will not be delivered at the surface of the soil, where evaporation is most rapid. The loss of water by evaporation within the soil at a depth of 3 or 4 inches is exceedingly slow.

Some years ago I saw some interesting soils in California. In some of the valleys they have soils that will produce a crop without any rainfall during the period of growth. At a point near Los Angeles, which I visited one September, they had a tobacco field which had been planted in April or May and had produced a crop which had been harvested. A sucker crop had been allowed to grow, and in September they were cutting this sucker crop, which had made a fair growth and was then in a very flourishing condition. The tobacco had had no rain since it was planted, but had been cultivated throughout the season as we do our crops in the East. With my hands I could scrape off the surface and get down to moist soil. The wells of that district showed the water table was 40 feet below the surface. Such an occurrence appears a very remarkable fact to us here in the East, where we suffer if the rain does not come within two or three weeks. In trying to find out a reason for those peculiar conditions in some of the western soils the fact presented itself that in those localities they have a very dry air, a very hot climate, and usually very strong winds that dry out the surface rapidly. They have about 18 or 20 inches of rain during the winter. After the rains

stop in April, if they immediately cultivate their surface soil and get it completely dried out, they thereby conserve the moisture, because any subsequent loss through evaporation will have to come from evaporation within the soil, and that is very slow, although slow evaporation does take place within a soil. If you fill a tumbler with moist soil and put it in the window in the sunshine you will find that the heat of the window sill will make the temperature of the bottom of the soil higher than the temperature of the surface; you will then get evaporation from the bottom, and the bottom soil will dry out quicker than the top.

When we dry out the surface through cultivation and maintain a dry earth mulch we force the place of evaporation from the surface down into the soil itself, and the water then has to evaporate within the soil and push its way up through these narrow spaces. Such diffusion is exceedingly slow. To test this idea of the cause of the peculiar conditions in the western soils I had a laboratory experiment tried on a small scale. Taking two cylinders 6 feet long we filled them with soil and placed the lower end of each in water. Over the surface of one tube we blew a current of air at the ordinary temperature and over the other we blew the same amount of air at a higher temperature, thus slightly heating the surface soil and creating conditions that favored evaporation. This forced the evaporation of the second soil, and for a short time it lost more than the other, but after the surface had dried out the evaporation from the tube was checked. During the twelve months the experiment was running the loss from the heated surface soil over which the dry air was blowing was very much less than from the other soil.

The trouble with our soils in the East seems to be that we have rain on an average every three days in the year. About one-third of our days are rainy days, according to the Weather Bureau reports. Of course we do not have rain every third day, but the average is that. The temperature is moderately warm, but the atmosphere is also quite humid as compared with the western climate. The evaporation from the surface of the soil is relatively slow; as fast as moisture is evaporated from the surface, water comes up by capillary action from below to take its place and is in turn evaporated. In the long run you will get a greater loss of water where the evaporation is slower than you will where the evaporation is more rapid. Is that point clear?

Mr. Walker. I see what you mean.

Professor Whitney. This is a fact which you can demonstrate for yourself. We use the principle every day in our kitchens. If we have a nice thick juicy steak to broil we put it so near the hot fire that the surface is rapidly dried and even slightly charred. This seals

the outside. Then we remove the meat to a cooler part of the flame, where we can cook it slowly, keeping the juices in. If that same steak is put on a slow fire and allowed to cook slowly from the start the juices evaporate and we get a dry, tough piece of meat. The more rapid the evaporation at the start the more we protect the juices in the meat.

Mr. Walker. During the period of our dry spells, in the case of corn, for example, would we get that result by continued cultivation or should we let the soil be? I mean under our conditions here, where we go down 45 feet for well water.

Professor Whitney. Conditions here are rather unfavorable for the control of moisture, because of our frequent rains. Strange as it may seem, while we suffer if we do not get rains, we should actually be better off, as they are in the arid regions of the West, if we did not have any rain during the growing season and had a means of providing water when we wanted it. There is no question that the arid conditions of agriculture with water for irrigation permit the most perfect system of cultivation. Such a system is much more efficient and crops are under much better control, if the conditions are handled intelligently, than they are here in the East. The trouble with us is that we can not maintain this dry mulch. After a rain we plow or cultivate just as soon as we can and we get the surface moderately dry; then another rain comes on and if we think we can afford it we cultivate again; then still another rain comes and we try again to get the surface dry. If you cultivate your soil after a rain just in the right time to catch the moisture in the soil, then if you have a drought, cultivate by all means; keep cultivating, and you will do much toward saving your crop. The Secretary of Agriculture has told of a very disastrous drought while he was professor of agriculture in Iowa, when he saved his corn crop and got a normal yield by constant cultivation during the dry season, while his neighbors had almost a complete failure. As I told you, it all depends upon the skill, the judgment, and the chance which lead you to begin operations just at the right time. If you knew what was coming you could save your crop during any ordinary period of drought.

Mr. Jefferson. Would you advocate deep plowing and shallow cultivation?

Professor Whitney. Deep plowing, certainly, and shallow cultivation. I am glad to see the tendency is to increase materially the depth of plowing in this neighborhood. A depth of 6 or 7 inches is an admirable preparation of the seed bed, but after that cultivation should be shallow.

POISONOUS ACTION OF WEEDS.

Another subject in this connection that may be interesting to you is the studies we have made on the cause of the deleterious effects of weeds in crops. It had formerly been supposed that they took a great deal of moisture and plant food from the soil. The fact of the matter is that if it were a mere matter of plant food we could all afford to put on an additional amount to provide for the weeds and also for the crops. In our gardens we could often go so far as to provide additional water, so that there would be sufficient both for the weeds and for the crops; but whether in the East, or in the West where they have irrigation systems, the weeds must be kept out, not because they use the water nor because they use the plant food, but because they are prejudicial to most crops. They have a poisonous effect on the crop. It is a case of incompatibility of association; they will not grow together. They poison each other. At Cornell University a very ingenious plan was devised for testing this idea of the influence of one plant on another. The plan has not been published, and I have just been advised of it, but as I remember it they took a long box, in one end of which they planted corn and in the other weeds. They had several of these boxes, so that they could vary the conditions. In one case they put a board partition between the corn and the weeds. The soil was similar in both cases. Where they had the partition between the corn and the weeds both crops grew normally; where there was no partition and the roots were allowed to intermingle the corn refused to grow—that is, it was materially retarded, or stunted, as we find it in weedy fields. The reason we keep out the weeds from our crops, especially during the early periods of growth, is not that they affect the moisture content, although they may do so, nor is it that they take up the plant food, but that their presence is obnoxious and apparently poisonous to the crop.

SMALL NUMBER OF STAPLE CROPS.

There is one other matter which I may call to your attention in the art of agriculture as we have it to-day, which is that we have comparatively few crops. We have a great variety of soils. In the soil survey we have encountered in the United States something over 400 types of soil. We are keeping the number down just as much as we can, being as conservative as possible in recognizing new types, but we have been forced to recognize 400 different soils, soils with different characters, soils undoubtedly adapted in some way to different crops. Now how many crops do you suppose we have to use on those 400 soils? The Bureau of Statistics reports on only about eight or ten staple crops. Did you ever realize how few crops we

have in general farming? Of course there are special industries like the citrus and pomaceous fruits, and special crops like celery and rhubarb, but comparatively few general crops.

Mr. Walker. Of staple crops only about eight or ten?

Professor Whitney. Yes; not over eight or ten. We have not enough crops, it seems to me, for the great variety of soils and the opportunity there is for diversification in the food of man and animals. Another thing, we are attempting to cultivate those staple crops on all kinds of soils, and we have at our command three recognized plant foods—potash, phosphoric acid, and nitrogen—and then we have lime, stable manure, green manure, clover, and cowpeas to counteract all the chemical ills the soil is heir to; for after all it is the soil we doctor, it is the soil we fertilize to prepare and fit for the crop.

USE OF LIME.

Mr. Walker. Just there—would you give us your idea about the value of lime applied on farm land?

Professor Whitney. I could not say that lime is generally beneficial. I do not think it is. I think lime should be used as a corrective of soil conditions, and unless the soil needs lime there is certainly no need of applying it. If the soil does need lime there are few other things that will take its place, and lime is the thing to apply. There are a great many soils that do not need lime. It is seldom used in the Middle West, never in the Far West. Lime is used principally in the Atlantic coast States; that is, in Pennsylvania, New Jersey, Delaware, Maryland, and Virginia. Those are the States that use more lime than probably all the other States of the Union. Did you ever realize that?

Mr. Walker. No.

Professor Whitney. They are just beginning to use lime in the Middle West. Ohio is in the lead. Illinois is using a little of the ground rock, but it is not in any general use in any of the States of the West. Lime is peculiarly needed by the States of the East, and especially by those that I have mentioned. In these Eastern States there are many soils that need lime. There are many soils that do not respond, showing that they do not need it. There are certain indications that point to the necessity of lime. The fact that clover does not grow well is not a sure indication, but it is an indication, because clover does not do well on an acid soil. I believe that lime may even be beneficial on a soil that is not really acid. The growth of moss is another indication of the need of lime. The appearance of sorrel—there is a little on your place, Mr. Walker—would also be an indication. These are all indications with which you are familiar.

Mr. Skipper. I would like to ask if you would consider the litmus-paper test a sure indication that soil would respond to or require lime?

Professor Whitney. No; I think it would be presumptive evidence that lime would be beneficial, but in the Bureau of Soils we have found that the reddening of blue litmus paper is not necessarily an indication of an acid soil or one which needs lime. The reddening of litmus paper may be due entirely to the remarkable absorptive properties possessed by certain soils. You can take an acid soil, or you can take a neutral or slightly alkaline soil, and put litmus paper in contact with it and it may redden it. But you can also take your blue litmus paper and absorbent cotton, wrap your litmus paper in the cotton and moisten it with perfectly pure boiled distilled water and leave it in contact, and in a short time the litmus paper will have turned red. This is due to the fact that blue litmus is a salt of an organic acid. The soil or the absorbent cotton has such an effect on the bases in the organic salt that they are withdrawn by the soil or cotton, leaving the acid in the paper, which thereby turns red. In other words, it splits up a chemical compound. This absorptive power is so remarkably strong in certain soils that they will actually break up silver nitrate and deposit silver in the soil as metallic flakes. The soil having absorbed the acid in contact with the silver has left the silver in its metallic state.

The physical and chemical forces in thin liquid films in contact with solid surfaces so minute as the soil grains are of an entirely different order from those we get in our laboratory beakers, and we are learning a new chemistry through our study of the soil. We are learning of new chemical forces that we had never dreamed of in our laboratory work. The soil has a remarkable power to change or dispose of things, aside from the bacterial agencies we know. The minerals that are present in the soil are not only not themselves decomposing in the sense of disappearing, but as some decompose others actually form. We can apply salt solutions to our soils and produce minerals similar to the minerals existing in rocks, a thing which is difficult if not impossible to do in our laboratories. The litmus test is not a sure indication of the acidity of a soil. It is not even a sure indication of the need of lime, although it seems to be an indication that would make it reasonably safe to apply lime to the land.

Mr. Skipper. The question of liming soils is a very interesting one to most of us and also a very important thing. What test would you advise the farmer to make to prove that his soil is deficient in lime or that his soil was neutral and did not require lime?

Professor Whitney. If you will turn to that basket method and test your soil with and without lime, in three weeks from now you will know whether lime is needed.

Mr. Skipper. That is a test you have found infallible?

Professor Whitney. We have found it in accordance with the experience of farmers.

Mr. Hurlock. How much lime would you put with that soil in a single pot?

Professor Whitney. You will find the amount stated in Circular No. 18, which I shall send you, and which contains other directions you will need in making the test.

Mr. Walker. How much lime do you use to the acre, Mr. Hurlock?

Mr. Hurlock. Thirty or forty bushels.

POT TEST AS INDICATOR OF CROP YIELD.

Mr. Walker. Now, Professor, the plants in that pot you have before you show a satisfactory growth. If it is followed out, will it develop grain in the same ratio? Have you conducted any tests of this kind?

Professor Whitney. We have conducted some tests in pots made in this same way, but much larger, and the indications we got at the start continued on up to the maturity of the plant—that is, the yield was of the same order as our ten-day test in the small pot. We have tested this method in connection with the plot experiments at the Rhode Island Experiment Station, and also at the Ohio Station, where they have had plots under observation for ten or twelve years, and the results that we get with these small pots in two weeks give the order of the differences they have got with the different fertilizers over a period of ten years. I believe these pot results will give you a relative indication of the number of bushels of grain the soils will produce. It is a safe indication of the relative order of efficiency of the fertilizers; but you must remember that we are dealing with the fertility of the soil and not with the yield, because the yield depends upon other things in addition to the fertility.

CONCLUDING REMARKS.

In conclusion, let me say that I have talked to you upon a very intricate, technical subject—the fertility of the soil and the way fertilizers act. I hope I have put this in such clear language that you will grasp the ideas that prevail at the present time in the minds of the able men that I have to assist me in this investigation. The question as to whether fertilizers act directly as plant foods or indirectly in improving the sanitary conditions of the soil—that is, whether the fertilizers act upon the plant food or act upon the soil—is, after all,

an academic question which has to be fought out and probably will be fought out among the eminent scientists of the world; for now the issue has been squarely taken and the matter will not be allowed to drop until a clearer solution of the question is reached. If you hear echoes of this scientific controversy, do not be disturbed by it, for it makes very little difference to you whether the fertilizer does act upon the plant or upon the soil. So long as we have fertilizers, and know that they are beneficial, the question of how they act can be safely left to scientific men. This much I will say, however, and will urge upon you, that the hypothesis that fertilizers act upon the soil rather than directly upon the plant in the sense of giving food to the plant, and the fuller insight into the economy of the soil which I have attempted to give you in this talk, make clearer to you practical men some of the difficult problems you all encounter in your fields. There is no question that these problems will be solved in time, but it will require a long time and earnest, conscientious work to solve many of the problems that you see upon your front lawns and in your cultivated fields. With the conception of soil fertility that I have presented, however, I think you will not feel so hopeless about some of your infertile soils if fertilizers do not act as you expect, and you will try to see if, through improved methods of cultivation or through other means which you have at your disposal, better results can not be accomplished than by the indiscriminate use of commercial fertilizers. I think, too, that with this paraffin-pot method the use of fertilizers will gradually assume a more rational and therefore a more generally profitable rôle in maintaining the fertility of your soils. I hope these ideas will remain with you, as some of these lines of thought are concerned with very practical problems that you are constantly confronting in the cultivation of your soils. I hope also that from this talk you may be able to see your way a little clearer toward the best art in the management of your soil.

25[illegible]

APPENDIX.

WIRE-BASKET METHOD FOR DETERMINING THE MANURIAL REQUIREMENTS OF SOILS.

The method of determining the manurial requirements of soils referred to in a preceding page consists in growing plants in small wire baskets containing soil to which have been added fertilizers of different kinds and in different quantities. The baskets, or pots, are planned to make possible a comparison of the several fertilizing ingredients within a period of about three weeks by means of the appearance and growth of the plants, or the effect of the treatments may be actually measured by cutting and weighing the plants or by measuring the transpiration during the period of growth.

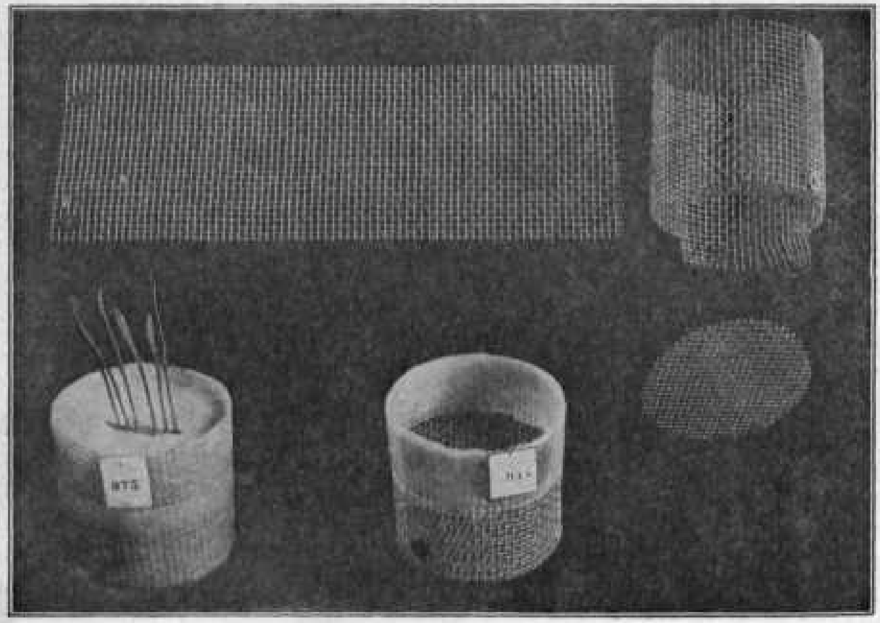

FIG. 1.—Construction of wire baskets.

In addition to the wire baskets, the construction of which is presently to be described, the necessary apparatus includes some paraffin, an inexpensive substance that can be procured from any drug store, and for the weighing tests a pair of scales which will weigh accurately to one-fourth ounce. The baskets, or pots, are made from galvanized-wire net having a one-eighth-inch mesh, and are of simple construction (see fig. 1). The net is cut into strips $3\frac{1}{2}$ inches wide by 10 inches long. The ends are brought together and fastened by short

rivets. At intervals along one end of the cylinder thus formed vertical incisions one-half inch long are made, and the ends are turned in to hold the bottom, which consists of a disk of the same material. The top of the basket is then dipped into hot paraffin to the depth of about 1 inch, removed, and dipped again, until a rim of paraffin is formed. Numbers are then attached to the pots for the purpose of identifying them, and in order that a record of each may be kept in case it is so desired. For convenience in handling it is advisable to place the pots in shallow boxes or trays, twenty, more or less, in each. This completes the construction of the wire pot up to the time of filling it with soil.

The soil to be tested should be representative of the field from which it is taken. A representative sample is usually secured by taking a number of small samples from different parts of the field and thoroughly mixing them together. From this mixture the portions that are to be treated with fertilizers are taken, the number of portions required being one greater than the number of kinds of treatment it is desired to test.

The quantity of fertilizer added should correspond closely to the quantity commonly used in field practice. To add these fertilizers in the proper proportions to the samples to be tested the following procedure is suggested: To 7¾ pounds of dry, well-pulverized soil add 1 ounce of the desired fertilizer. Mix very thoroughly and pass through a sieve at least twice. This mixture is still much too strong for use, and is further diluted by adding 1 ounce of it to 5 pounds more of soil, mixing thoroughly, as before. This new mixture contains fertilizer at the rate of 200 pounds per acre. When larger applications are desired, proportionally larger quantities of the first mixture should be taken. For the lime treatment use only 11½ ounces of soil to 1 of lime instead of 7¾ pounds, as in the case of fertilizers. Cowpea vines and manure, being used in even greater quantity than the lime, require a still further reduction of the amount of soil in the first mixture, i. e., 4 ounces of soil to 1 of cowpea vines and 1½ ounces of soil to 1 of manure. One ounce of each of these mixtures when added to 5 pounds of soil will supply lime at the rate of 1 ton, cowpea vines 5 tons, and manure 10 tons per acre.

The following table shows the treatments commonly used in the work, but these are often varied to suit conditions, and any commercial fertilizer which it is desired to test may be added to the list:

1. Untreated.
2. Dry manure, 5 tons per acre.
3. Lime, 1 ton per acre.
4. Nitrate of soda, 200 pounds per acre.
5. Sulphate of potash, 200 pounds per acre.
6. Acid phosphate, 200 pounds per acre.
7. Nitrate of soda and sulphate of potash, 200 pounds each per acre.
8. Nitrate of soda and acid phosphate, 200 pounds each per acre.
9. Sulphate of potash and acid phosphate, 200 pounds each per acre.
10. Nitrate of soda, sulphate of potash, and acid phosphate, 200 pounds each per acre.
11. Nitrate of soda, sulphate of potash, and acid phosphate, 200 pounds each per acre, + lime, 2,000 pounds per acre.
12. Cowpeas, 5,000 pounds per acre, + lime, 2,000 pounds per acre.

After the fertilizers have been added to the soil it is allowed to remain in pans or other suitable receptacles for several days, being moistened occasionally with rain water or water from melted ice and frequently stirred, so that the fertilizers may become thoroughly distributed. At the end of this time the

soil in each pan is moistened again with water, which is added until the soil is in the most favorable condition for plant growth. This varies with different soils, but with a little experience the operator can judge it quite accurately. It is important that the water used in moistening the soil should be rain water, as water from wells, springs, or streams may contain mineral matter that would affect the plants, and thus vitiate the results of the tests. The soil in each pan is then divided into five nearly equal parts, and each part is placed in a wire basket, care being taken to press the soil well into the bottom and sides of the basket. The basket should be filled to within about one-half inch of the top. After filling, the soil which projects through the meshes of the wire is carefully brushed off, and the baskets are ready for planting.

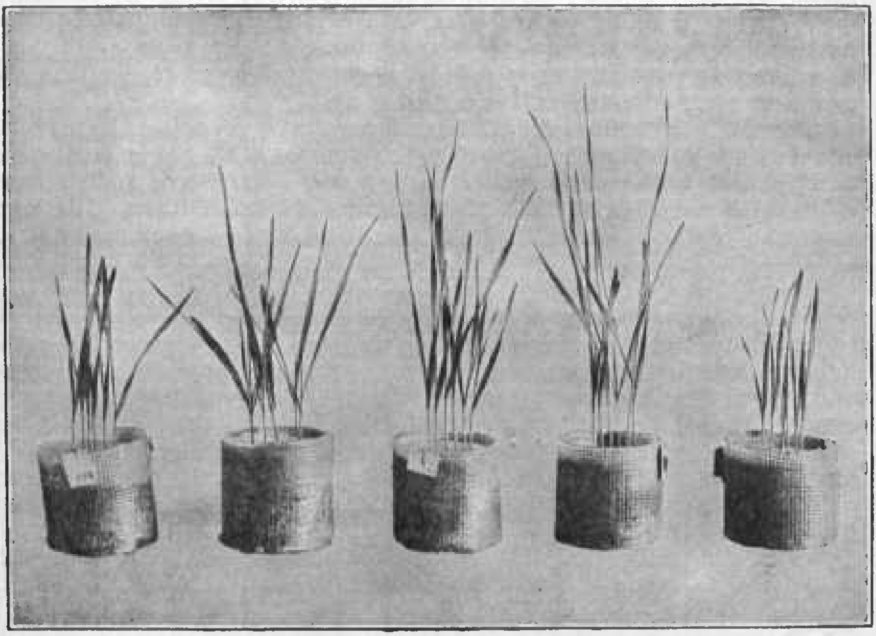

FIG. 2.—Finished baskets and growing plants.

One or two days before the time for planting a sufficient quantity of wheat is placed between moist cloths, covered with wet sand, and placed in a favorable place for germination. From these sprouted wheat grains those of uniform size and about the same stage of development are selected, six being planted in a row and to the same depth in each basket. The surface of the soil is then covered to a depth of about one-fourth inch with clean dry sand. The pots are then dipped bottom down into hot paraffin until an impervious layer is formed over the lower part of the basket, connecting with the rim around the top. In coating the basket the paraffin is kept at an even temperature and the basket is dipped and quickly removed to allow the paraffin to harden, when it is dipped again, and so on until the coating has the proper thickness, about one-sixteenth of an inch. The baskets are then placed where they will be under as favorable conditions of light, temperature, and moisture as possible, care being taken to keep the pots of each set together.

The pots should be watered at frequent intervals during the growth of the plants, care being taken not to allow them to become too dry nor to make them too wet. As a guide to the amount of water required by the pots it is a wise precaution to weigh and record the weight of some of the pots when they are paraffined and planted, at which time the moisture content of the soil is favorable. By weighing these pots at intervals during the tests the amount of water necessary to bring the soil to a favorable condition can be ascertained and an equal amount added to all other baskets that show an equal growth.

At the end of fifteen or twenty days a comparison of the growth of the plants will enable one to estimate the value of the different fertilizers. (Fig. 2.)

It should be borne in mind that this is a method not for the study of the requirements of plants, but for the study of the fertilizer requirements of soils, in which the plants are used as an indicator. It is, therefore, not necessary to grow the plants to maturity; in fact, it would not be possible to do so successfully in the small quantity of soil used. Where differences occur as a result of the fertilizer they manifest themselves almost from the beginning of plant growth, and it is not necessary or advisable to grow the plants for periods of time exceeding twenty or twenty-five days from the date of planting the seed.

FARMERS' BULLETINS.

The following is a list of the Farmers' Bulletins available for distribution, showing the number and title of each. Copies will be sent to any address on application to any Senator, Representative, or Delegate in Congress, or to the Secretary of Agriculture, Washington, D. C.

No. 22. The Feeding of Farm Animals. No. 24. Hog Cholera and Swine Plague. No. 25. Peanuts: Culture and Uses. No. 27. Flax for Seed and Fiber. No. 28. Weeds: And How to Kill Them. No. 29. Souring and Other Changes in Milk. No. 30. Grape Diseases on the Pacific Coast. No. 32. Silos and Silage. No. 33. Peach Growing for Market. No. 34. Meats: Composition and Cooking. No. 35. Potato Culture. No. 36. Cotton Seed and Its Products. No. 37. Kafir Corn: Culture and Uses. No. 39. Onion Culture. No. 41. Fowls: Care and Feeding. No. 43. Sewage Disposal on the Farm. No. 44. Commercial Fertilizers. No. 46. Irrigation in Humid Climates. No. 47. Insects Affecting the Cotton Plant. No. 48. The Manuring of Cotton. No. 49. Sheep Feeding. No. 51. Standard Varieties of Chickens. No. 52. The Sugar Beet. No. 54. Some Common Birds. No. 55. The Dairy Herd. No. 56. Experiment Station Work—I. No. 58. The Soy Bean as a Forage Crop. No. 59. Bee Keeping. No. 60. Methods of Curing Tobacco. No. 61. Asparagus Culture. No. 62. Marketing Farm Produce. No. 63. Care of Milk on the Farm. No. 64. Ducks and Geese. No. 65. Experiment Station Work—II. No. 66. Meadows and Pastures. No. 68. The Black Rot of the Cabbage. No. 69. Experiment Station Work—III. No. 70. Insect Enemies of the Grape. No. 71. Essentials in Beef Production. No. 72. Cattle Ranges of the Southwest. No. 73. Experiment Station Work—IV. No. 74. Milk as Food. No. 77. The Liming of Soils. No. 78. Experiment Station Work—V. No. 79. Experiment Station Work—VI. No. 80. The Peach Twig-borer. No. 81. Corn Culture in the South. No. 82. The Culture of Tobacco. No. 83. Tobacco Soils. No. 84. Experiment Station Work—VII. No. 85. Fish as Food. No. 86. Thirty Poisonous Plants. No. 87. Experiment Station Work—VIII. No. 88. Alkali Lands. No. 91. Potato Diseases and Treatment. No. 92. Experiment Station Work—IX. No. 93. Sugar as Food. No. 95. Good Roads for Farmers. No. 96. Raising Sheep for Mutton. No. 97. Experiment Station Work—X. No. 98. Suggestions to Southern Farmers. No. 99. Insect Enemies of Shade Trees. No. 100. Hog Raising in the South. No. 101. Millets. No. 102. Southern Forage Plants. No. 103. Experiment Station Work—XI. No. 104. Notes on Frost. No. 105. Experiment Station Work—XII. No. 106. Breeds of Dairy Cattle. No. 107. Experiment Station Work—XIII. No. 108. Saltbushes. No. 109. Farmers' Reading Courses. No. 110. Rice Culture in the United States. No. 111. Farmers' Interest in Good Seed. No. 112. Bread and Bread Making. No. 113. The Apple and How to Grow It. No. 114. Experiment Station Work—XIV. No. 115. Hop Culture in California. No. 116. Irrigation in Fruit Growing. No. 118. Grape Growing in the South. No. 119. Experiment Station Work—XV. No. 120. Insects Affecting Tobacco. No. 121. Beans, Peas, and other Legumes as Food. No. 122. Experiment Station Work—XVI. No. 123. Red Clover Seed: Information for Purchasers. No. 124. Experiment Station Work—XVII. No. 125. Protection of Food Products from Injurious Temperatures. No. 126. Practical Suggestions for Farm Buildings. No. 127. Important Insecticides. No. 128. Eggs and Their Uses as Food. No. 129. Sweet Potatoes. No. 131. Household Tests for Detection of Oleomargarine and Renovated Butter. No. 132. Insect Enemies of Growing Wheat. No. 133. Experiment Station Work—XVIII. No. 134. Tree Planting in Rural School Grounds. No. 135. Sorghum Sirup Manufacture. No. 136. Earth Roads. No. 137. The Angora Goat. No. 138. Irrigation in Field and Garden. No. 139. Emmer: A Grain for the Semiarid Regions. No. 140. Pineapple Growing. No. 141. Poultry Raising on the Farm. No. 142. Principles of Nutrition and Nutritive Value of Food. No. 143. Conformation of Beef and Dairy Cattle. No. 144. Experiment Station Work—XIX. No. 145. Carbon Bisulphid as an Insecticide. No. 146. Insecticides and Fungicides. No. 147. Winter Forage Crops for the South. No. 148. Celery Culture. No. 149. Experiment Station Work—XX. No. 150. Clearing New Land. No. 151. Dairying in the South. No. 152. Scabies in Cattle. No. 153. Orchard Enemies in the Pacific Northwest. No. 154. The Home Fruit Garden: Preparation and Care. No. 155. How Insects Affect Health in Rural Districts. No. 156. The Home Vineyard. No. 157. The Propagation of Plants. No. 158. How to Build Small Irrigation Ditches. No. 159. Scab in Sheep. No. 161. Practical Suggestions for Fruit Growers. No. 162. Experiment Station Work—XXI. No. 164. Rape as a Forage Crop. No. 165. Culture of the Silkworm. No. 166. Cheese Making on the Farm. No. 167. Cassava. No. 168. Pearl Millet. No. 169. Experiment Station Work—XXII. No. 170. Principles of Horse Feeding. No. 171. The Control of the Codling Moth. No. 172. Scale Insects and Mites on Citrus Trees. No. 173. Primer of Forestry. No. 174. Broom Corn. No. 175. Home Manufacture and Use of Unfermented Grape Juice. No. 176. Cranberry Culture. No. 177. Squab Raising. No. 178. Insects Injurious in Cranberry Culture. No. 179. Horseshoeing. No. 181. Pruning. No. 182. Poultry as Food. No. 183. Meat on the Farm—Butchering, Curing, etc. No. 184. Marketing Live Stock. No. 185. Beautifying the Home Grounds. No. 186. Experiment Station Work—XXIII. No. 187. Drainage of Farm Lands. No. 188. Weeds Used in Medicine. No. 190. Experiment Station Work—XXIV. No. 192. Barnyard Manure. No. 193. Experiment Station Work—XXV. No. 194. Alfalfa Seed. No. 195. Annual Flowering Plants. No. 196. Usefulness of the American Toad. No. 197. Importation of Game Birds and Eggs for Propagation. No. 198. Strawberries. No. 199. Corn Growing. No. 200. Turkeys. No. 201. Cream Separator on Western Farms. No. 202. Experiment Station Work—XXVI. No. 203. Canned Fruits, Preserves, and Jellies. No. 204. The Cultivation of Mushrooms. No. 205. Pig Management. No. 206. Milk Fever and its Treatment. No. 208. Varieties of Fruits Recommended for Planting. No. 209. Controlling the Boll Weevil in Cotton Seed and at Ginneries. No. 210. Experiment Station Work—XXVII. No. 211. The Use of Paris Green in Controlling the Cotton Boll Weevil. No. 212. The Cotton Bollworm—1904. No. 213. Raspberries. No. 215. Alfalfa in the Eastern States. No. 216. Control of the Cotton Boll Weevil. No. 217. Essential Steps in Securing an Early Crop of Cotton. No. 218. The School Garden. No. 219. Lessons taught by the Grain-Rust Epidemic of 1904. No. 220. Tomatoes. No. 221. Fungous Diseases of the Cranberry. No. 222. Experiment Station Work—XXVIII. No. 223. Miscellaneous Cotton Insects in Texas. No. 224. Canadian Field Peas. No. 225. Experiment Station Work—XXIX. No. 226. Relation of Coyotes to Stock Raising in the West. No. 227. Experiment Station Work—XXX. No. 228. Forest Planting and Farm Management. No. 229. The Production of Good Seed Corn. No. 230. Game Laws for 1905. No. 231. Spraying for Cucumber and Melon Diseases. No. 232. Okra: Its Culture and Uses. No. 233. Experiment Station Work—XXXI. No. 234. The Guinea Fowl and Its Use as Food. No. 235. Cement Mortar and Concrete. No. 236. Incubation and Incubators. No. 237. Experiment Station Work—XXXII. No. 238. Citrus Fruit Growing in Gulf States. No. 239. The Corrosion of Fence Wire. No. 240. Inoculation of Legumes. No. 241. Butter Making on the Farm. No. 242. An Example of Model Farming. No. 243. Fungicides and Their Use in Preventing Diseases of Fruits. No. 244. Experiment Station Work—XXXIII. No. 245. Renovation of Worn-out Soils. No. 246. Saccharine Sorghums for Forage. No. 247. The Control of the Codling Moth and Apple Scab. No. 248. The Lawn. No. 249. Cereal Breakfast Foods. No. 250. The Prevention of Stinking Smut of Wheat and Loose Smut of Oats. No. 251. Experiment Station Work—XXXIV. No. 252. Maple Sugar and Sirup. No. 253. Germination of Seed Corn. No. 254. Cucumbers. No. 255. The Home Vegetable Garden. No. 256. Preparation of Vegetables for the Table. No. 257. Soil Fertility. No. 258. Texas, or Tick, Fever and Its Prevention. No. 259. Experiment Station Work—XXXV.

JUNE 1, 1906.

O